FUEL SYSTEM

LIQUID FUEL SPECIFICATIONS AND FUEL PROPERTY ISSUES

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Properties of oil Fuels

Flash Point	Density
Specific gravity	Viscosity
Pour point	Specific heat
Calorific value	Sulphur content
Ash content	Carbon residue
Water content	Carbon/ Hydrogen ratio
Relative Cost	Storage of fuels

✓ Density

- Ratio of the fuel's mass to its volume at 25 °C,
- kg/m^3
- Useful for determining fuel quantity and quality

✓ Specific gravity

- Ratio of weight of oil volume to weight of same water volume at a given temperature
- Specific gravity of water is 1
- Measured by using Hydrometer

Fuel oil type	LDO (Light Diesel Oil)	Furnace oil	LSHS (Low Sulphur Heavy Stock)
Specific Gravity	0.85-0.87	0.89-0.95	0.88-0.98

✓ Viscosity

- Measure of fuel’s internal resistance to flow, Most important characteristic for storage and use, Decreases as temperature increases

✓ Flash point

- Lowest temperature at which a fuel can be heated so that the vapor gives off flashes when an open flame is passes over it.
- Or, The lowest temperature at which it can vaporize to form an ignitable mixture in air.

✓ Pour point

- Lowest temperature at which fuel will flow, Indication of temperature at which fuel can be pumped

✓ Specific heat

- kCal needed to raise temperature of 1 kg oil by 1°C (kcal/kg°C)
- Indicates how much steam/electricity it takes to heat oil to a desired temperature

✓ Calorific value

- Heat or energy produced per Kg of Fuel
- Gross calorific value (GCV): water vapor is fully condensed
- Net calorific value (NCV): water vapor is not fully condensed

Fuel Oil	Gross Calorific Value (kCal/kg)
Kerosene	11,100
Diesel Oil	10,800
L.D.O (*Light Diesel Oil)*	10,700
Furnace Oil	10,500
LSHS (*Low sulphur Heavy Stock)*	10,600

✓ Sulphur content

- Depends on source of crude oil and less on the refining process
- Furnace oil: 2-4 % sulphur
- Sulphuric acid causes corrosion

✓ Ash content

- Inorganic material in fuel
- Typically 0.03 - 0.07%
- Corrosion of burner tips and damage to materials /equipments at high temperatures

✓ Carbon residue

- Tendency of oil to deposit a carbonaceous solid residue on a hot surface
- Residual oil: >1% carbon residue

✓ Water content

- Normally low in furnace oil supplied (<1% at refinery)
- Free or emulsified form
- Can damage furnace surface and impact flame

✓Relative Cost

Although there is a clear price differential in favor of the residual oils, the capital investment in the storage system, handling and combustion equipment for residual fuel oils is significantly higher than that needed for distillate oils.

✓ Storage of fuels

- Store in cylindrical tanks above or below the ground
- Recommended storage: >10 days of normal consumption
- Cleaning at regular intervals

Typical specifications of fuel oils

Properties	*Fuel Oils*		
	Furnace Oil	*L.S.H.S*	*L.D.O*
Density (Approx. g/cc at 150C)	**0.89-0.95**	**0.88-0.98**	**0.85-0.87**
Flash Point (0C)	**66**	**93**	**66**
Pour Point (0C)	**20**	**72**	**18**
G.C.V. (Kcal/kg)	**10500**	**10600**	**10700**
Sediment, % Wt. Max.	**0.25**	**0.25**	**0.1**
Sulphur Total, % Wt. Max.	**< 4.0**	**< 0.5**	**< 1.8**
Water Content, % Vol. Max.	**1.0**	**1.0**	**0.25**
Ash % Wt. Max.	**0.1**	**0.1**	**0.02**

Vapor Density (V.D.)

Definition: Weight of a vapor or gas compared to an equal volume of air (air = 1). If greater than 1.0, the vapor or gas is heavier than air and will concentrate in the low places. If less than 1.0, the vapor or gas will rise up.

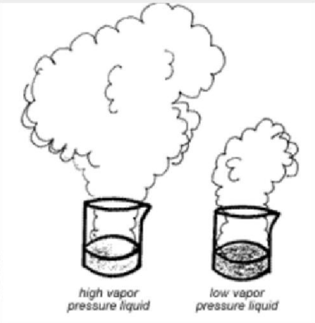
Example:

Ammonia	0.59
Ethylene	0.97
Hydrogen sulfide	1.19
Trichloroethylene	4.50
Methylene chloride	2.90
Benzene	2.70
Gasoline	4.40

Importance: Important because most vapors from toxic materials and many flammable materials are heavier than air and will accumulate in low lying areas.

Vapor Pressure (V.P.)

Definition: The tendency for a solid or liquid to evaporate into the air (MSDS lists this property in millimeters mercury(mmHg) at 68°F). The lower the boiling point, the higher the vapor pressure.



Example:

	BP(°F)	VP(mmHg)
Chlorine	-29	> atmosphere
Methylene Chloride	104	350
Acetone	133	180
Trichloroethylene	189	58
Xylene	269	9
Styrene	293	5
Cadmium	1409	0

Importance: Material with high vapor pressure will enter the air quickly and could overcome an entrant who is not protected. Also, the higher the vapor pressure or a sealed chemical container, the more likely it is to explode as the temperature rises

Volatility

Definition: It refers to how readily a material will evaporate into the air (vaporize). Volatility increases as the temperature increases.

Example: Gasoline is a volatile liquid; lubricating oil is not.

Importance: Volatile liquids can give off vapors which may be harmful to your health. Some volatile materials can produce a vapor heavier than air (high vapor density) that can creep along the ground and fill up manholes, trenches, or other low-lying areas. The vapor forces out oxygen and can result in death by asphyxiation. Some vapor concentrations are explosive and flammable.

Temp. With $C = 5/9(F - 32)$

Toxicity

Definition: Toxic chemicals can harm workers by skin contact, inhalation, ingestion, or injection through the skin.

Example :
Skin contact hazard : Acids and alkalis
Inhalation hazard : Methyl bromide and solvents
Ingestion hazard: Radioactive materials and solvents

Importance: The worker has the right to know the health effects of the chemicals identified within the permit space. The EPA has a specific definition of "toxic" and lists of toxic hazardous wastes. It is important to remember that all substances which may cause harm are not on the official lists.

Autoignition Temperature

Definition: The lowest temperature at which a flammable gas / vapor-air mixture will ignite from its own heat source or contact with a heated surface without needing a spark or flame. Vapors and gases will spontaneously ignite at a lower temperature in pure oxygen than in air (21 % oxygen)

Example:

Acetone	1000°F	(537°C)
Toluene	997°F	(536°C)
Benzene	12°F	(-11°C)
Methane	-306°F	(188°C)

Importance: Autoignition temperatures of chemicals may be lowered by other substances in a permit space. Methane may be produced by decaying organic material.

Explosive Limits

- The explosive concentration of vapors in air has a lower and upper limit.
  - The **Lower Explosive Limit (LEL)** is the lowest concentration that will ignite.
  - The **Upper Explosive Limit (UEL)** is the highest concentration that will ignite.
  - If the vapor concentration is between the LEL and UEL, there is serious risk of fire or explosion.

Explosive Limits

Above the Upper Explosive Limit, the mixture is too rich to burn

UPPER EXPLOSIVE LIMIT

Explosive Range

LOWER EXPLOSIVE LIMIT

Below the Lower Explosive Limit, the mixture is too lean to burn

Flammable, Combustible, and Ignitable

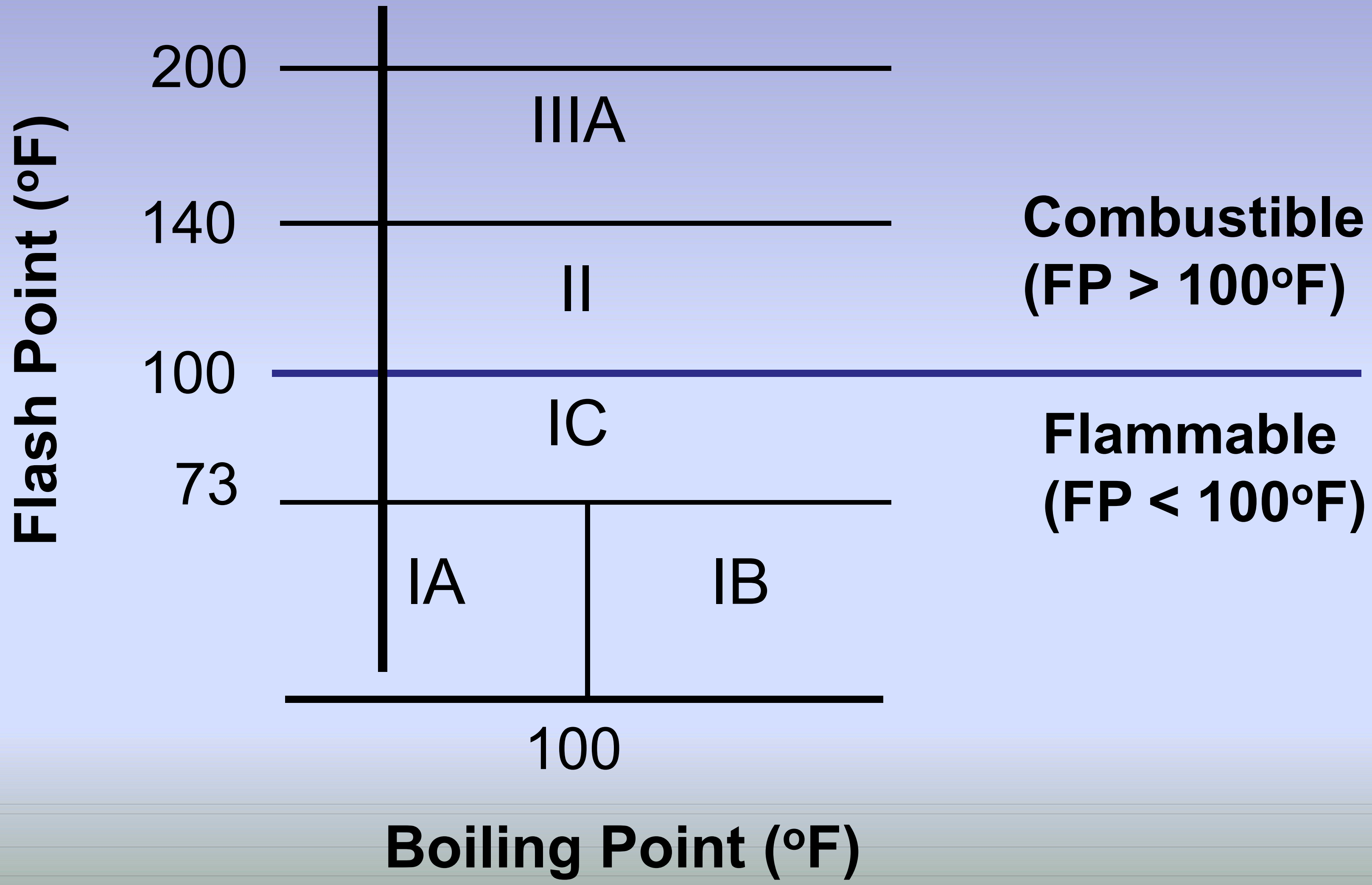
- **Flash point** means the minimum temperature at which a liquid gives off enough vapor to form an ignitable mixture.

In general, the lower flash point fuel is the greater hazard.

- **Combustible liquids** have flash points at or above 100°F 37.78 °C.
- **Flammable liquids** have flash points below 100 °F, and are more dangerous than combustible liquids, since they may be ignited at room temperature.

http://www.csgnetwork.com/tempconv.html

Classes of Flammable and Combustible Liquids



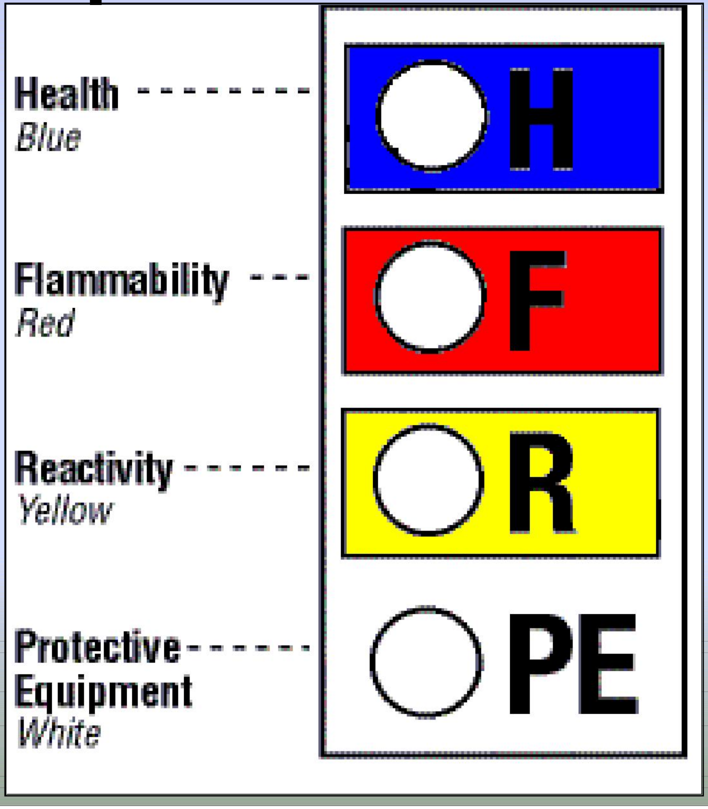
Classes of Some Flammable Liquids Fuel

	Common Name	Flash Point (°F)
CLASS IA	Ethyl Ether	-49
CLASS IB	Gasoline	-45
	Methyl Ethyl Ketone	21
	Toluene	40
CLASS IC	Xylene	81-115
	Turpentine	95

Flammable Liquids

- **Flammable liquids** can cause a fire or explosion, and like many other substances, they can also cause serious health effects from overexposure.

Note: On the NFPA(National Fire Protection Association) diamond label, a fire hazard rating of 3 or 4 denotes a flammable liquid.



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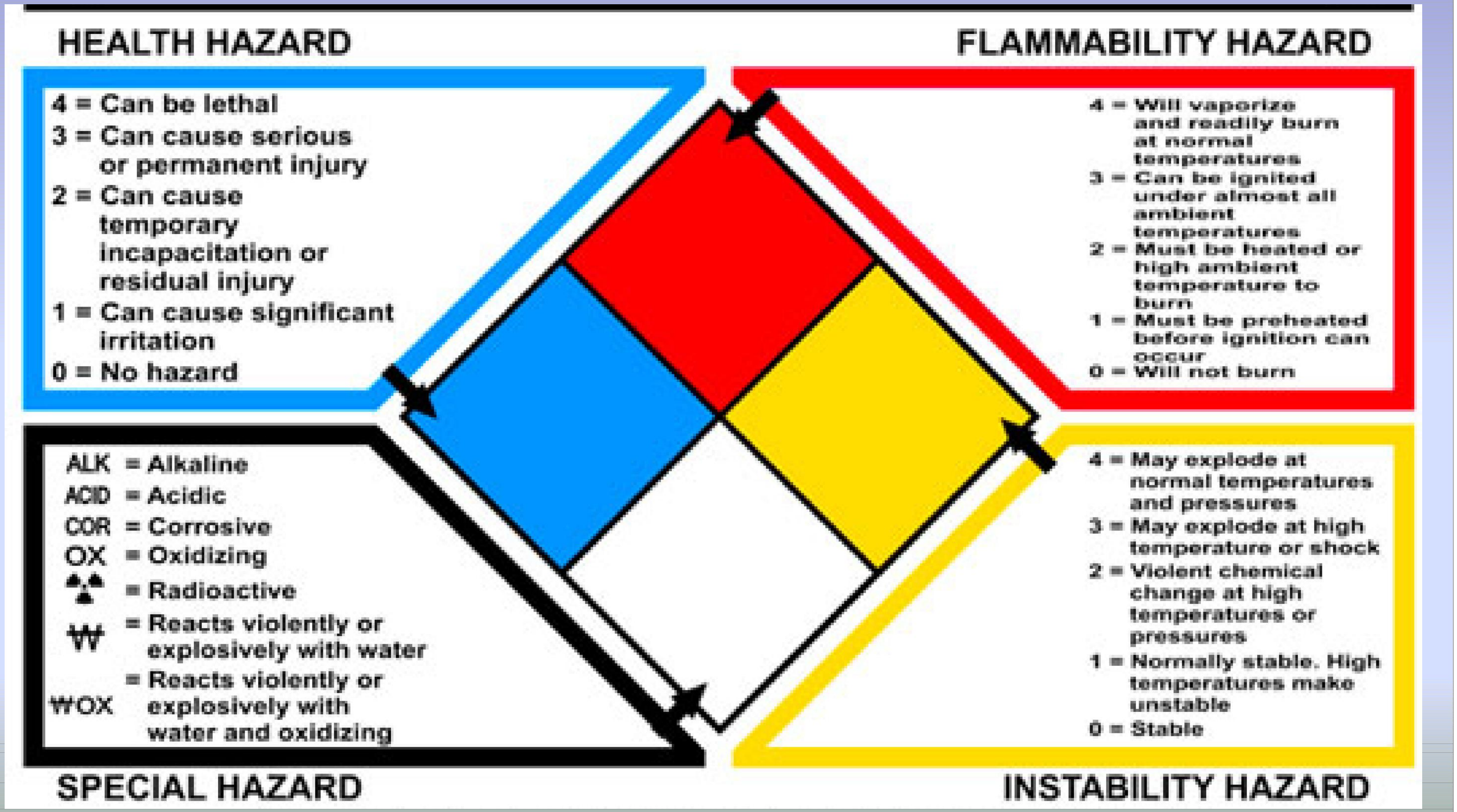


HEALTH HAZARD

4 = Can be lethal
3 = Can cause serious or permanent injury
2 = Can cause temporary incapacitation or residual injury
1 = Can cause significant irritation
0 = No hazard

FLAMMABILITY HAZARD

4 = Will vaporize and readily burn at normal temperatures
3 = Can be ignited under almost all ambient temperatures
2 = Must be heated or high ambient temperature to burn
1 = Must be preheated before ignition can occur
0 = Will not burn

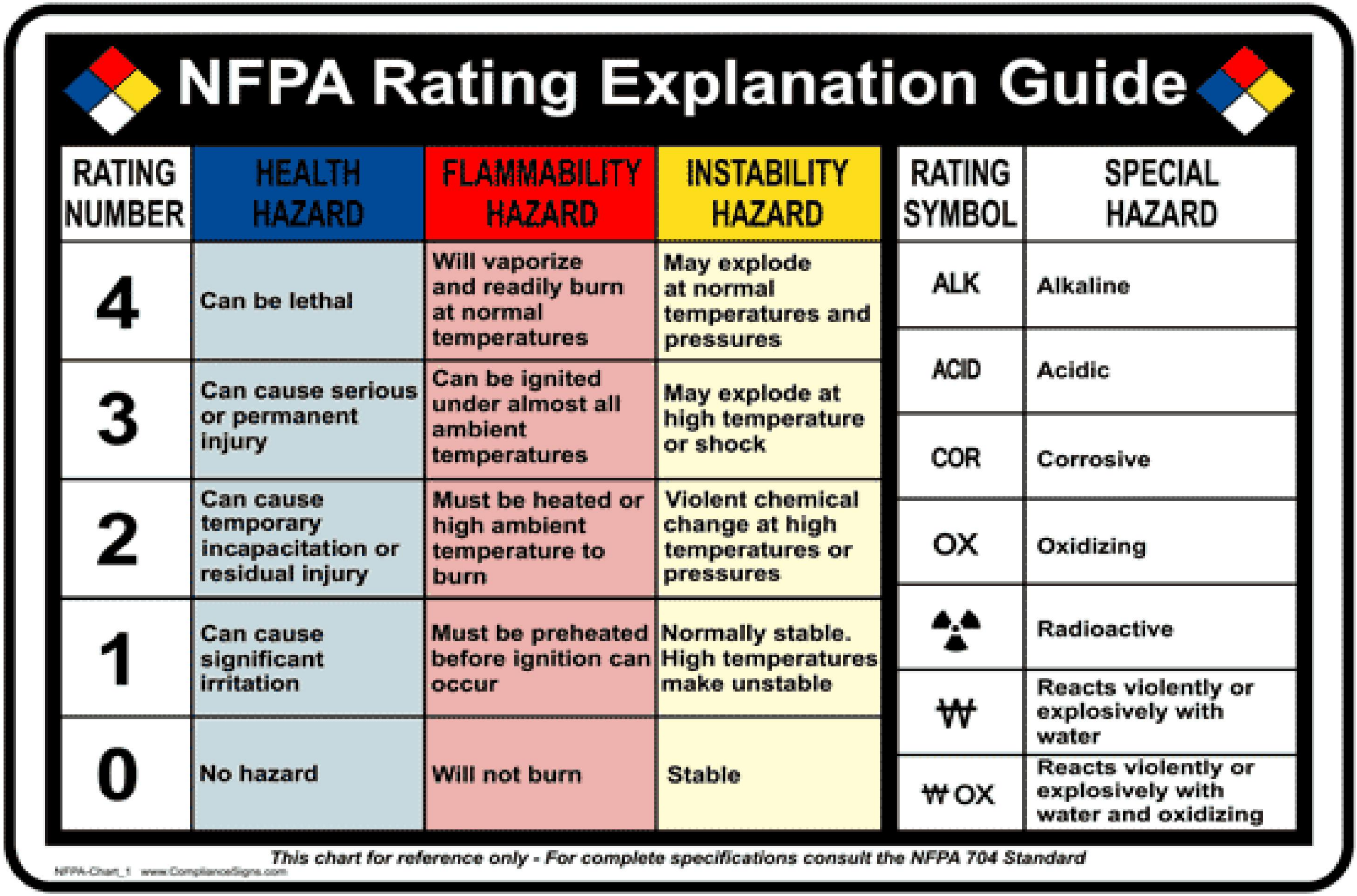
SPECIAL HAZARD

ALK = Alkaline
ACID = Acidic
COR = Corrosive
OX = Oxidizing
☢ = Radioactive
₩ = Reacts violently or explosively with water
₩OX = Reacts violently or explosively with water and oxidizing

INSTABILITY HAZARD

4 = May explode at normal temperatures and pressures
3 = May explode at high temperature or shock
2 = Violent chemical change at high temperatures or pressures
1 = Normally stable. High temperatures make unstable
0 = Stable

NFPA(National Fire Protection Association



NFPA Rating Explanation Guide

RATING NUMBER	HEALTH HAZARD	FLAMMABILITY HAZARD	INSTABILITY HAZARD
4	Can be lethal	Will vaporize and readily burn at normal temperatures	May explode at normal temperatures and pressures
3	Can cause serious or permanent injury	Can be ignited under almost all ambient temperatures	May explode at high temperature or shock
2	Can cause temporary incapacitation or residual injury	Must be heated or high ambient temperature to burn	Violent chemical change at high temperatures or pressures
1	Can cause significant irritation	Must be preheated before ignition can occur	Normally stable. High temperatures make unstable
0	No hazard	Will not burn	Stable

RATING SYMBOL	SPECIAL HAZARD
ALK	Alkaline
ACID	Acidic
COR	Corrosive
OX	Oxidizing
☢	Radioactive
₩	Reacts violently or explosively with water
₩ OX	Reacts violently or explosively with water and oxidizing

This chart for reference only - For complete specifications consult the NFPA 704 Standard

NFPA-Chart_1 www.ComplianceSigns.com

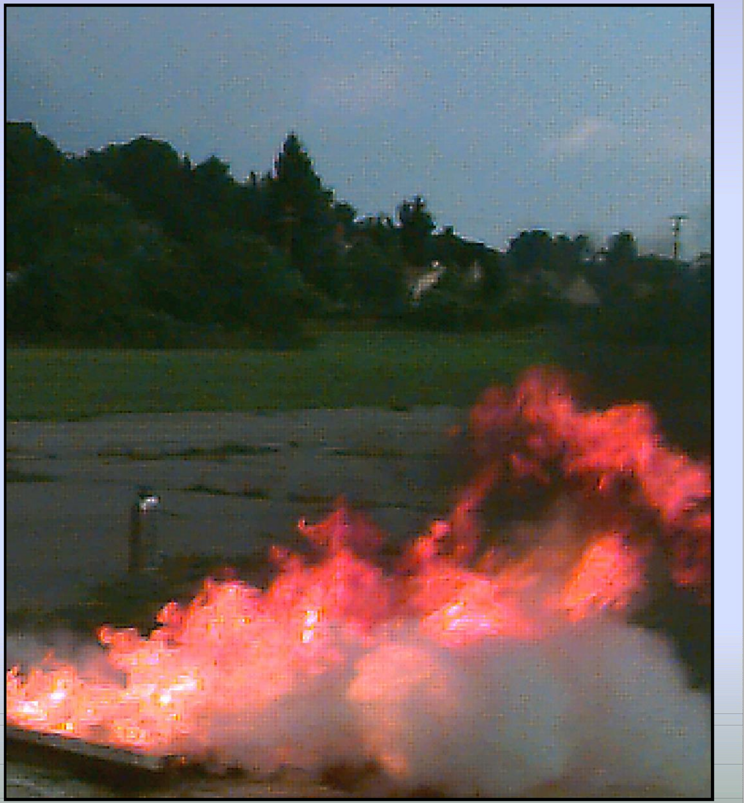
Flammable Liquids

- A **flammable liquid** is any liquid having a flashpoint below 100°F.
  - Exception: Any mixture having components with flashpoints of 100°F or higher, the total of which make up 99% or more of the total volume of the mixture.

Note: The flash point is the lowest temperature at which a liquid gives off enough vapor to form a flammable mixture with air.

Flammable Liquids

- The vapors of flammable liquids often present the most serious hazard.
  - The vapors can easily ignite or explode.
  - Flammable liquid vapors are heavier than air and may settle in low spots, or move a significant distance from the liquid itself.



Combustion of Liquid Fuels Principals……………………..(1)

- **For efficient combustion, a liquid fuel must be broken up into a stream of droplets to maximize the surface area-to-volume ratio.**

- **The various types of burner accomplish this in different ways, but the objective of all types of burner is to produce a spray of droplets which are small, and which have a narrow size distribution.**

Combustion of Liquid Fuels Principals……………………..(2)

- The combustion process consists of evaporation of the droplet, driven by heat transfer from its surroundings, with the vapor subsequently burning in a diffusion flame.

- A classical analysis of this situation where the heat transfer to the droplet is by convection shows that the rate of mass transfer (and hence the combustion rate of the droplet) is inversely proportional to the diameter.

Combustion of Liquid Fuels Principals……………………..(3)

- Because evaporation of the droplet is the controlling influence on the, liquids with low latent heats of evaporation will burn more quickly.

- The combustion of a liquid fuel spray is more complex in particular, heat transfer to the droplet will happened by radiation as well as convection in some application.

Combustion of Liquid Fuels Principals…………………….(4)

- The combustion of oil is a two phase process.

- Intimate mixing of the fuel and air is an important requirement hence the fuel is broken up into a fine spray, or atomized.

GASOLINE CHEMICAL IDENTITY

1. **Gasoline is a refined product of petroleum consisting of a mixture of hydrocarbons, additives, and blending agents.**

2. **The composition of gasoline varies widely, depending on the crude oils used, the refinery processes available, the overall balance of product demand, and the product specifications.**
3. **The typical composition of gasoline hydrocarbons (% volume) is as follows:**

4-8% alkanes; 2-5% alkenes; 25-40% isoalkanes;
3-7% cycloalkanes; l-4% cycloalkenes; and 20-50% total aromatics
(0.5-2.5% benzene)

Additives and blending agents are added to the hydrocarbon mixture to improve the performance and stability of gasoline , :-

- **Anti-Knock Agents (AKA),**

chemical compounds added in small quantities (less than 1 percent) to motor fuels to improve the antiknock ratings of the fuels. The best-known antiknock agents are tetraethyllead (TEL) $Pb(C_2H_5)_4$, tetramethyllead $Pb(CH_3)_4$, methylcyclopentadienyl manganese tricarbonyl $CH_3C_5H_4Mn(CO)_3$, and pentacarbonyli-ron $Fe(CO)_5$.

For all the familiar antiknock compounds, only TEL is widely employed in the form of ethyl fluid. Motor fuels containing TEL are called ethylated, or leaded. Leaded fuels are highly toxic; safety measures are mandatory when working with them.

Additives and blending agents are added to the hydrocarbon mixture to improve the performance and stability of gasoline , :-

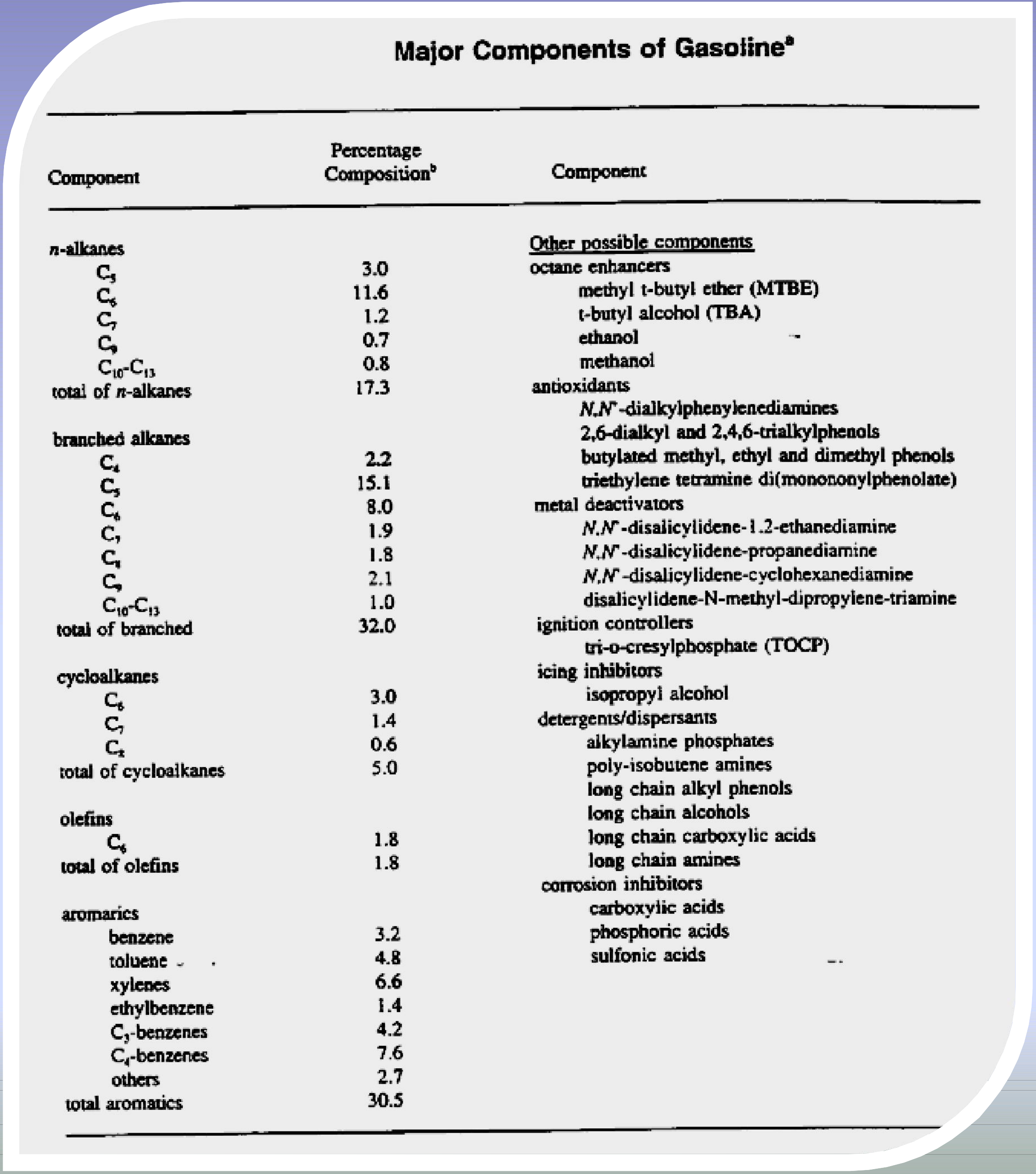
Anti-oxidants, **metal deactivators**, **lead scavengers**, anti-rust agents, **anti-icing agents**, upper-cylinder lubricants, **detergents**, and dyes.

At the end of the production process, finished gasoline typically contains more than **150 separate compounds** although as many as 1,000 compounds have been identified in some blends.

Gasoline varies from 83% to 87% carbon

and

11% to 14% hydrogen by weight.



Major Components of Gasoline[a]

Component	Percentage Composition[b]	Component
n-alkanes		Other possible components
C_5	3.0	octane enhancers
C_6	11.6	methyl t-butyl ether (MTBE)
C_7	1.2	t-butyl alcohol (TBA)
C_9	0.7	ethanol
C_{10}-C_{13}	0.8	methanol
total of *n*-alkanes	17.3	antioxidants
		N,N'-dialkylphenylenediamines
branched alkanes		2,6-dialkyl and 2,4,6-trialkylphenols
C_4	2.2	butylated methyl, ethyl and dimethyl phenols
C_5	15.1	triethylene tetramine di(monononylphenolate)
C_6	8.0	metal deactivators
C_7	1.9	*N,N'*-disalicylidene-1,2-ethanediamine
C_8	1.8	*N,N'*-disalicylidene-propanediamine
C_9	2.1	*N,N'*-disalicylidene-cyclohexanediamine
C_{10}-C_{13}	1.0	disalicylidene-N-methyl-dipropylene-triamine
total of branched	32.0	ignition controllers
		tri-o-cresylphosphate (TOCP)
cycloalkanes		icing inhibitors
C_6	3.0	isopropyl alcohol
C_7	1.4	detergents/dispersants
C_8	0.6	alkylamine phosphates
total of cycloalkanes	5.0	poly-isobutene amines
		long chain alkyl phenols
olefins		long chain alcohols
C_6	1.8	long chain carboxylic acids
total of olefins	1.8	long chain amines
		corrosion inhibitors
aromatics		carboxylic acids
benzene	3.2	phosphoric acids
toluene	4.8	sulfonic acids
xylenes	6.6	
ethylbenzene	1.4	
C_3-benzenes	4.2	
C_4-benzenes	7.6	
others	2.7	
total aromatics	30.5	

Front-end Volatility

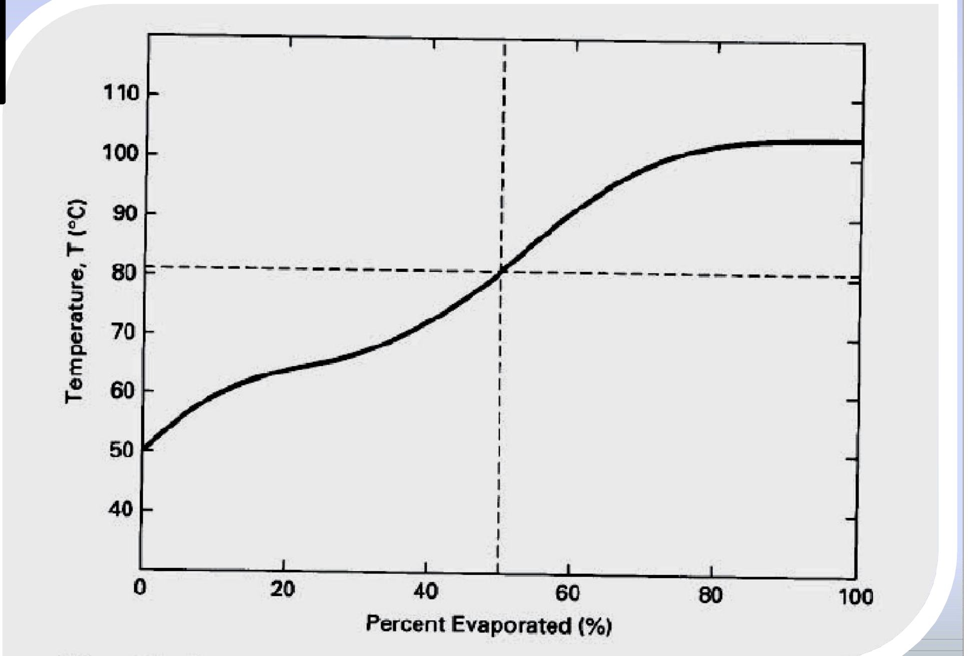
Can cause problems when the fuel vaporizes too quickly. volumetric efficiency of the engine will be reduced if fuel vapor replaces air too early in the intake system

Vapor Lock

Fuel vaporizes in the fuel supply lines or in the carburetor in the hot engine compartment.

High-end Volatility

To maximize volumetric efficiency, some of the fuel should not vaporize until late into the compression stroke and even into the start of combustion.



Gasoline volatility curves

Gasoline volatility Can be expressed by the Three Temperature

One way that is sometimes used to describe a gasoline is to use **three temperatures:** the temperature at which 10% is vaporized, at which **50%** is vaporized, and at which **90%** is vaporized.

For Example classified as 57-81-103°C

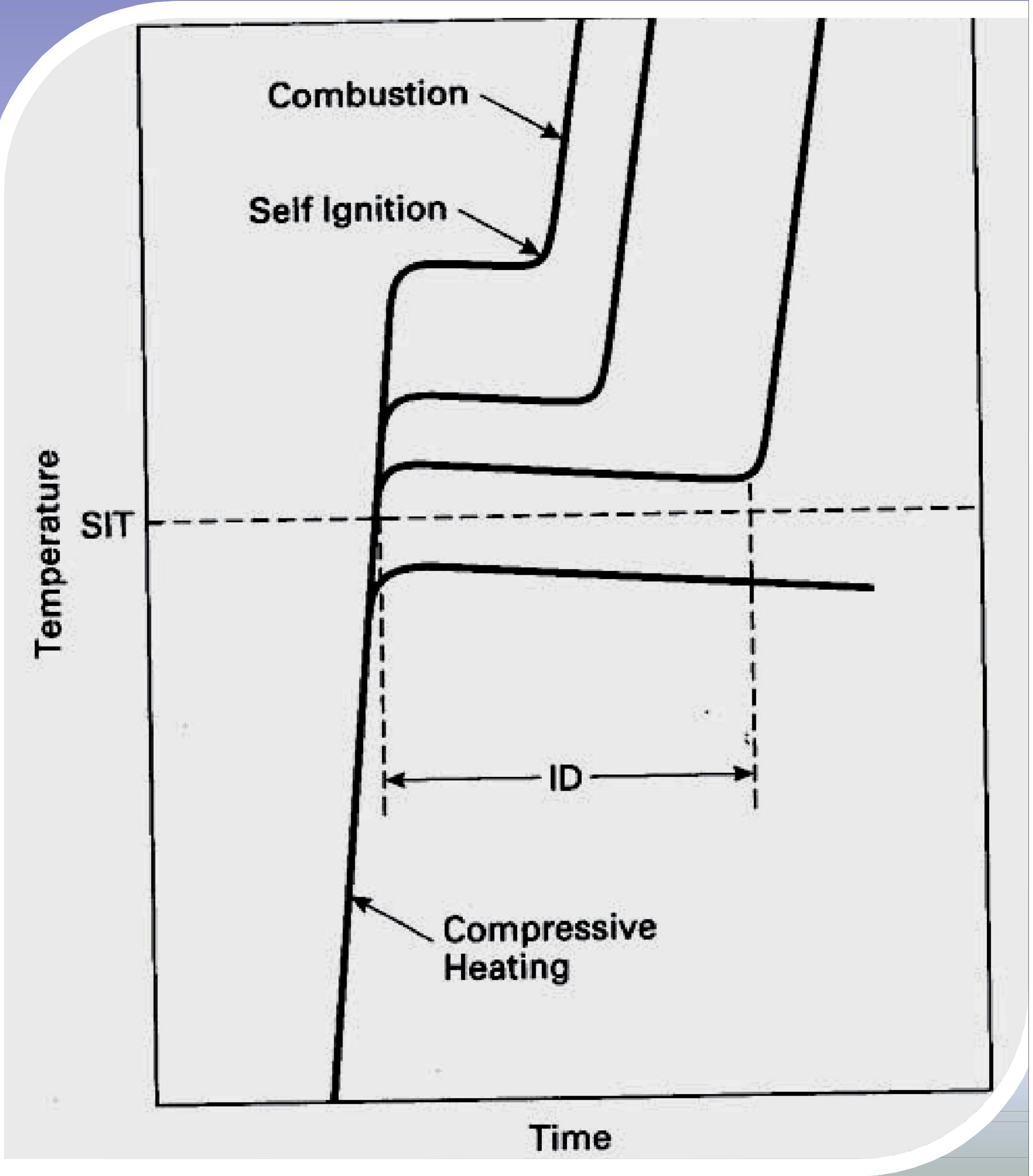
SELF-IGNITION AND Engine Knock & Detonation

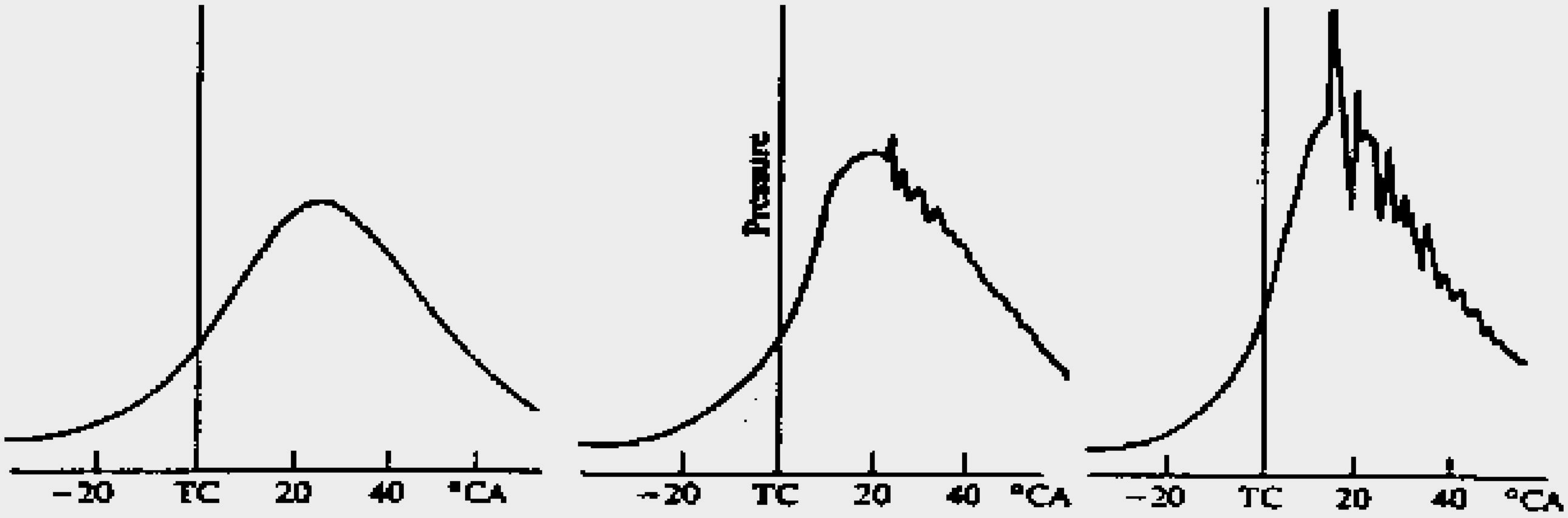
- **Self-ignition temperature (SIT)**

- **The compression ratios of gasoline-fueled SI engines are limited to about 11:1 to avoid self-ignition**

Self-ignition

characteristics of fuels. If the temperature of a fuel is raised above the self-ignition temperature (SIT), the fuel will spontaneously ignite after a short ignition delay (ID) time. The higher above SIT which the fuel is heated, the shorter will be ID. Ignition delay is generally on the order of thousandths of a second

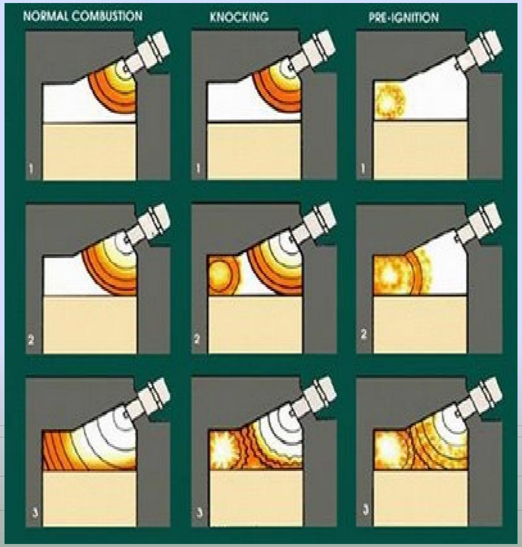


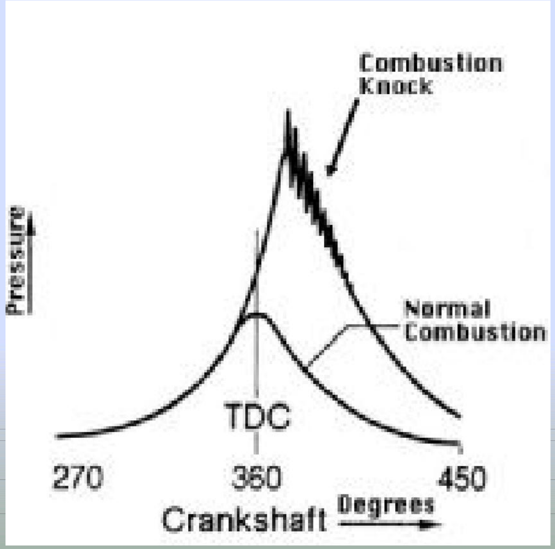


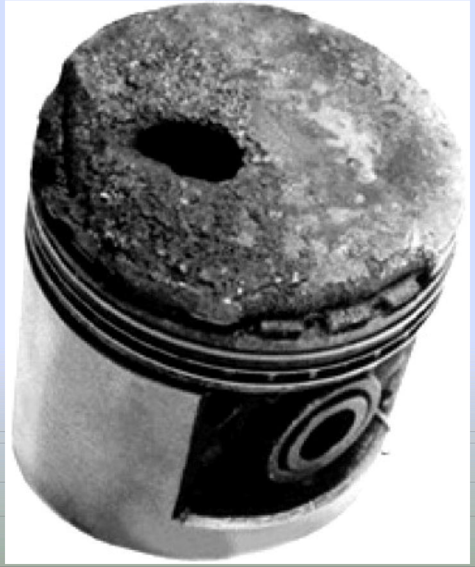
(*a*) Normal combustion, spark 28°BTC

(*b*) Slight knock, spark 28°BTC

(*c*) Intense knock, spark 32°BTC







Octane Number and Engine Knock

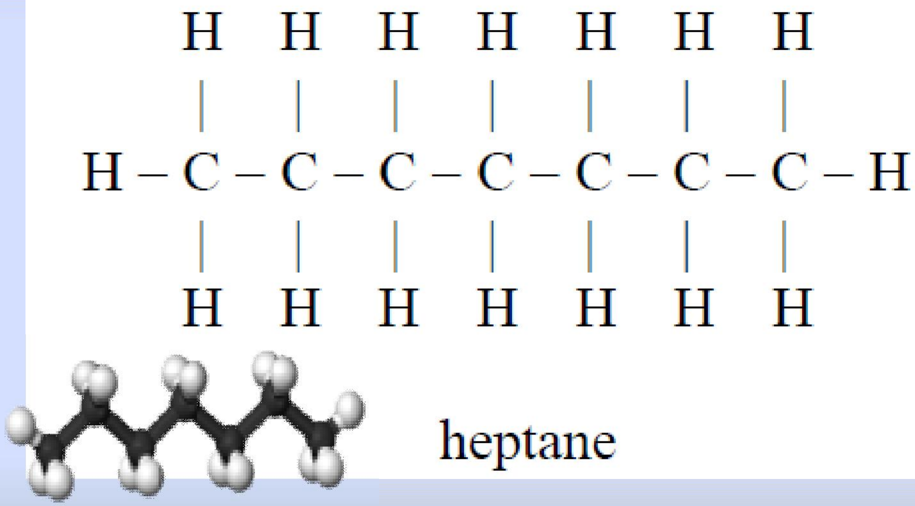
- The octane number is a measure of the tendency of a fuel to auto-ignite. The lower the octane rating(number) the more likely it is that auto-ignition will occur.

- Engines with low compression ratios can use fuels with lower octane numbers, but high-compression engines must use high-octane fuel to avoid self-ignition and knock.

Octane number equates to the anti-knock qualities of a comparison mixture of heptane and isooctane which is expressed as the percentage of isooctane in heptane

Heptane has a high tendency to auto-ignite, so it was given an octane number of 0.

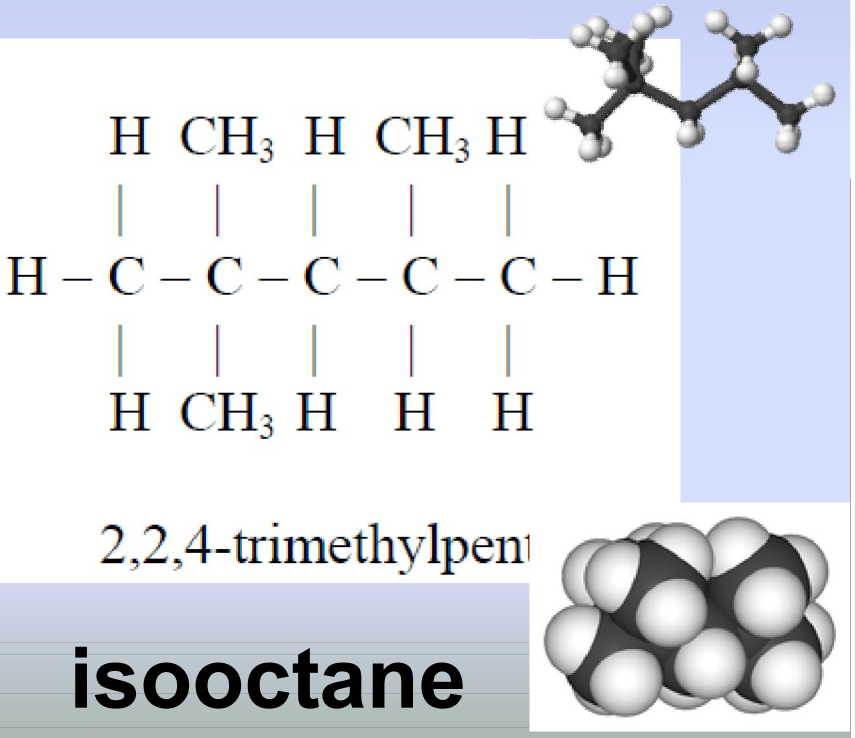
2,2,4-trimethylpentane has a low tendency to auto-ignite, so it was given a rating of 100.



$$\begin{array}{ccccccccc} & H & H & H & H & H & H & H & \\ & | & | & | & | & | & | & | & \\ H- & C- & C- & C- & C- & C- & C- & C & -H \\ & | & | & | & | & | & | & | & \\ & H & H & H & H & H & H & H & \end{array}$$

heptane

n-heptane



$$\begin{array}{ccccccc} & H & CH_3 & H & CH_3 & H & \\ & | & | & | & | & | & \\ H- & C- & C- & C- & C- & C & -H \\ & | & | & | & | & | & \\ & H & CH_3 & H & H & H & \end{array}$$

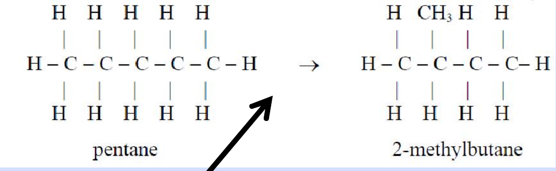
2,2,4-trimethylpent

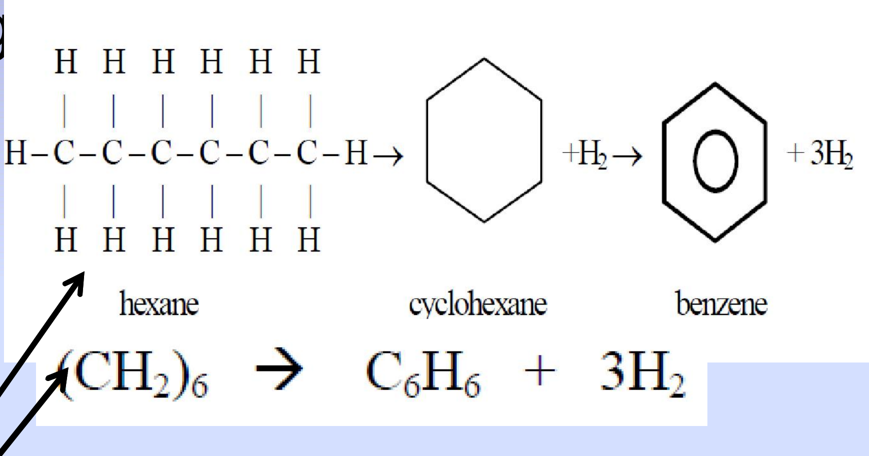
isooctane

HIGH OCTANE COMPOUNDS

Knocking may also be prevented by using a mixture of high-octane compounds in petrol manufacture.

- a) A high degree of branching
- b) Short chain length
- c) The existence of rings.

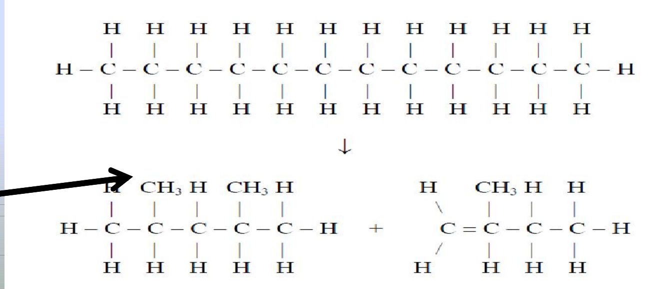




$(CH_2)_6 \rightarrow C_6H_6 + 3H_2$

High-octane compounds can be obtained from low by three processes, each involving the use of catalysts:

- a) Isomerisation
- b) Dehydrocyclisation
- c) Catalytic cracking.



Measurement methods

Research Octane Number (RON)

RON is determined by running the fuel in a test engine with a variable compression ratio under controlled conditions, and comparing the results with those for mixtures of iso-octane and n-heptane.

Motor Octane Number (MON) or Aviation Octane Number (AON).

Motor Octane Number (MON), or the AON which is a better measure of how the fuel behaves when under ENGINE or Aircraft load

Anti-Knock Index (AKI) sometimes called the Pump Octane Number (PON).

AKI =PON= (MON + RON)/2

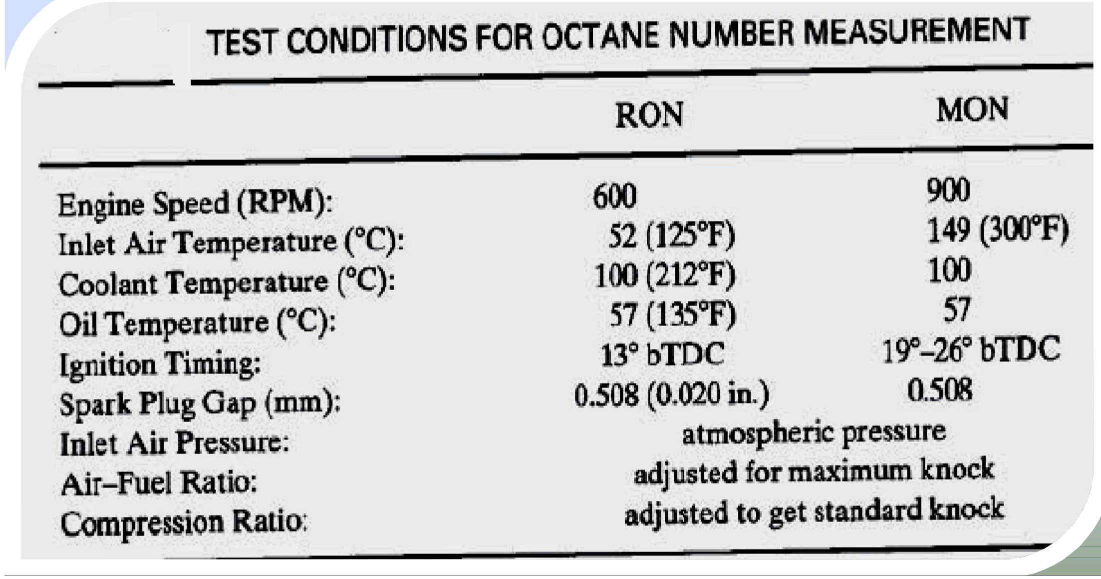
Observed Road Octane Number (RdON)

Fuel sensitivity:

FS = RON - MON

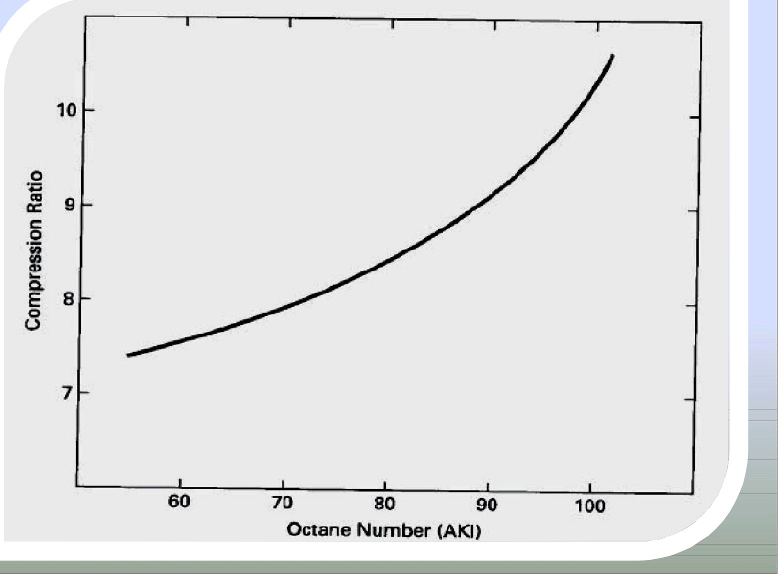
Fuel sensitivity is a good measure of how sensitive knock characteristics of a fuel will be to engine geometry. A low FS number will usually mean that knock characteristics of that fuel are insensitive to engine geometry.

FS numbers generally range from 0 to 10.

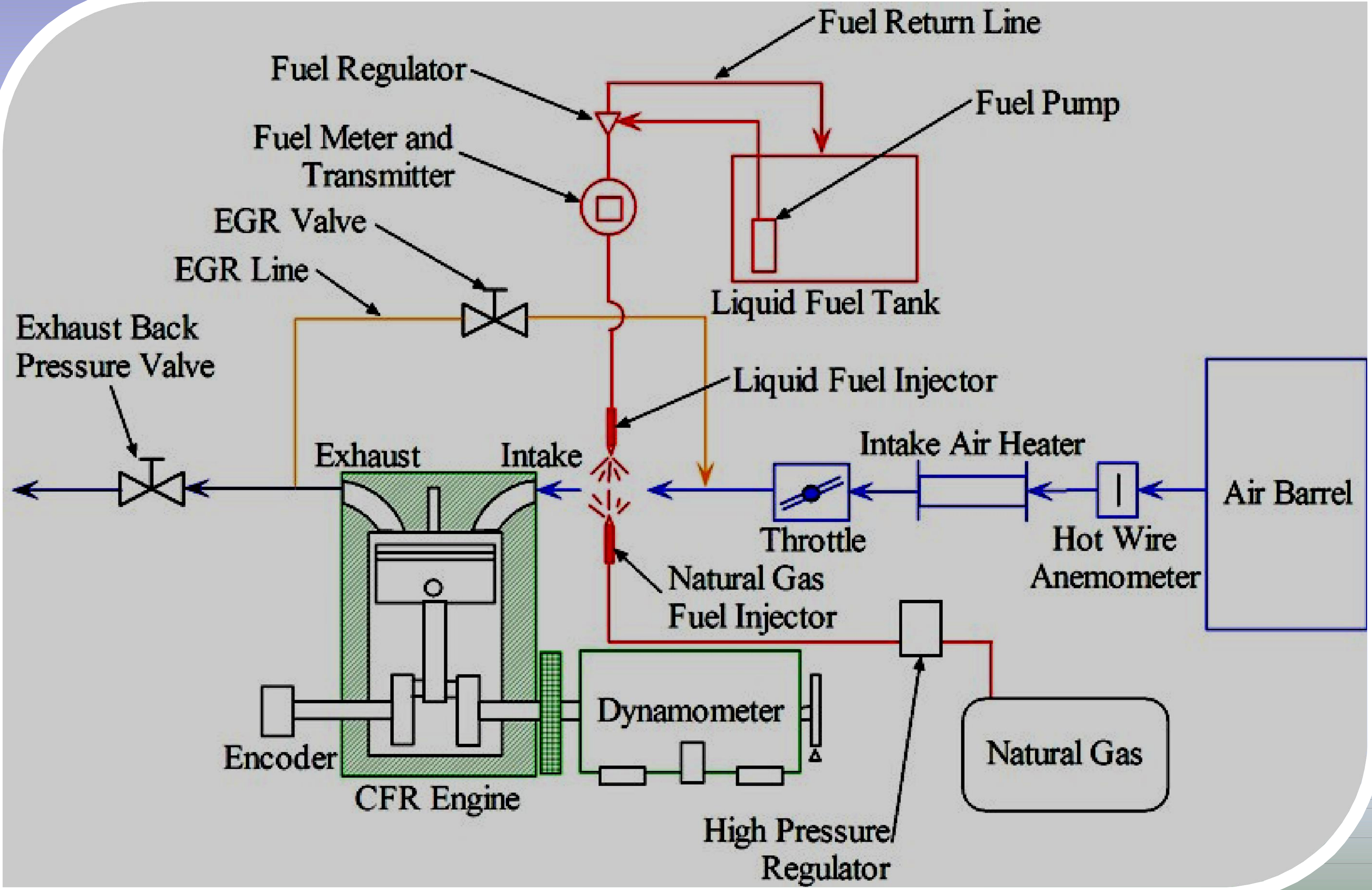


TEST CONDITIONS FOR OCTANE NUMBER MEASUREMENT

	RON	MON
Engine Speed (RPM):	600	900
Inlet Air Temperature (°C):	52 (125°F)	149 (300°F)
Coolant Temperature (°C):	100 (212°F)	100
Oil Temperature (°C):	57 (135°F)	57
Ignition Timing:	13° bTDC	19°–26° bTDC
Spark Plug Gap (mm):	0.508 (0.020 in.)	0.508
Inlet Air Pressure:	atmospheric pressure	
Air–Fuel Ratio:	adjusted for maximum knock	
Compression Ratio:	adjusted to get standard knock	



CFR Co-operative Fuel Research



National Institute for Occupational Safety and Health

Thank you!

National Institute for Occupational Safety and Health

Thank you!